Dynamically Consistent Estimates of Diabatic Heating

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1. Introduction

Despite its central role in climate and climate variability, a detailed knowledge of diabatic heating rates remains elusive. In this study a long-term dataset of tropospheric heating rates has been generated by diagnosing heating, *H*, as a residual term in the heat budget

$$H = \frac{\partial T}{\partial t} + \mathbf{v} \cdot \nabla T - \sigma\omega \tag{1}$$

by specifying the NCEP Reanalysis horizontal wind fields and temperatures on the right hand side. The vertical motion, ω, is, however, not taken directly from the NCEP Reanalysis, but is instead diagnosed from the large-scale vorticity budget

$$\frac{\partial \zeta}{\partial t} + \mathbf{v} \cdot \nabla(\zeta + f) - (\zeta + f)\omega_p + curl\left(\omega\frac{\partial \mathbf{v}}{\partial p}\right) + dissipation = R = 0 \tag{2}$$

An improved version of the iterative procedure described in Sardeshmukh (1993) has been applied to the NCEP Reanalysis wind fields to minimize the vorticity budget residual *R*, and the divergent circulation is further constrained to satisfy the large-scale mass budget. The procedure is applied to twice-daily reanalysis fields in the 1969-1999 period. Figure 1 is a typical plot of how *R* decreases with iteration as a fraction of the initial residual at different vertical levels.

We have found that enforcing dynamical consistency on the divergent circulation has a noticeable effect on the strength, position, and variability of the diagnosed heating extrema. Comparisons with field experiments also yield encouraging results. In the following sections we refer to our dynamically consistent heating fields as “chi-corrected” fields.

2. Results

The chi-corrected and NCEP Reanalysis monthly mean global heating fields for January 1993 are shown in Figure 2. Monthly means have been calculated from twice-daily heating analyses integrated from the surface to 200 hPa. While the large-scale patterns are similar in these two fields, important differences are evident. For example, the magnitude of the chi-corrected heating is larger in the Indo-Pacific corridor and central Pacific and smaller over southern Africa and the Indian Ocean. Sub-tropical cooling is also stronger in the chi-corrected dataset.

The heating fields are similar to independent observational estimates of precipitation (Fig. 2c), but cannot be expected to be identical since diabatic heating and cooling are not strictly due to the release of latent heat. In particular, these fields show that the absence or presence of precipitation in a region (e.g., in the Atlantic storm track; off the coast of West Africa) is not always a good indicator of the sign or magnitude of the heating in that region.

The interannual standard deviation of January monthly mean column-integrated heating for 1969-1997 is shown in Figure 3. The dynamically consistent fields show more extensive heating variability than that produced by the NCEP Reanalysis, particularly in the Tropics. Increases to the variability in the central equatorial Pacific are due primarily to increases in the strength of the diagnosed heating during ENSO events. Enhanced variability is also evident along the SPCZ. It should be noted that stronger variability is present in the chi-corrected dataset on all resolved time scales and seasons, not just for the subset of parameters shown here.

The vertical profiles of the chi-corrected heat source, Q1, and moisture sink, Q2, during the Intensive Observing Period (1 Nov. 1992 - 28 Feb. 1993) of TOGA-COARE are in better agreement with observations than those derived from the NCEP Reanalysis (Fig. 4). Note in particular that the chi-corrected fields now have a nearly identical estimation of the deep convective heating profile Q1 and the correct sign for Q2 near the surface. The observed data is an updated version of Johnson and Lin's (1997) dataset for the Intensive Flux Array (IFA) region of COARE. The NCEP Reanalysis and chi-corrected data were taken from an analysis gridpoint near the center of the IFA region (1.4S, 155E).

3. Conclusions

In the Tropics, the chi-corrected dynamically consistent heating fields show substantially greater variability than the uncorrected fields on all resolved time scales. The vertical profiles of diabatic heating and moistening from the corrected reanalyses for the northern winter of 1992-93 compare better with profiles from COARE, than do the profiles from the original reanalyses.

In the absence of "Diabatic Heating Meters" for directly measuring heating rates in the atmosphere, the approach followed here provides perhaps the most complete diagnosis of global heating rates, with relatively little contamination from a data-assimilating model's parameterizations. This twice-daily global dataset of dynamically consistent heating fields for 1969 to the present will be made available on the web at http://www.cdc.noaa.gov/chi/.

4. References

Johnson, R. H., and X. Lin, 1997: Episodic trade wind regimes over the western Pacific warm pool. *J. Atmos. Sci.*, **54**, 2020-2034.

Sardeshmukh, P. D., 1993: The baroclinic chi problem and its application to the diagnosis of atmospheric heating rates. *J. Atmos. Sci.*, **50**, 1099-1112.

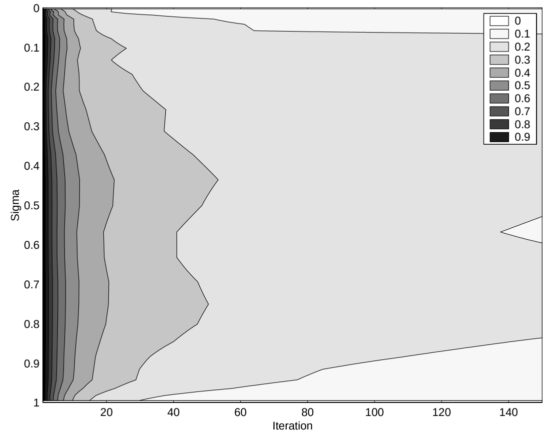

Fig. 1. The vorticity budget residual *R* at each level expressed as a fraction of the initial vorticity imbalance for each iteration of the minimization problem.

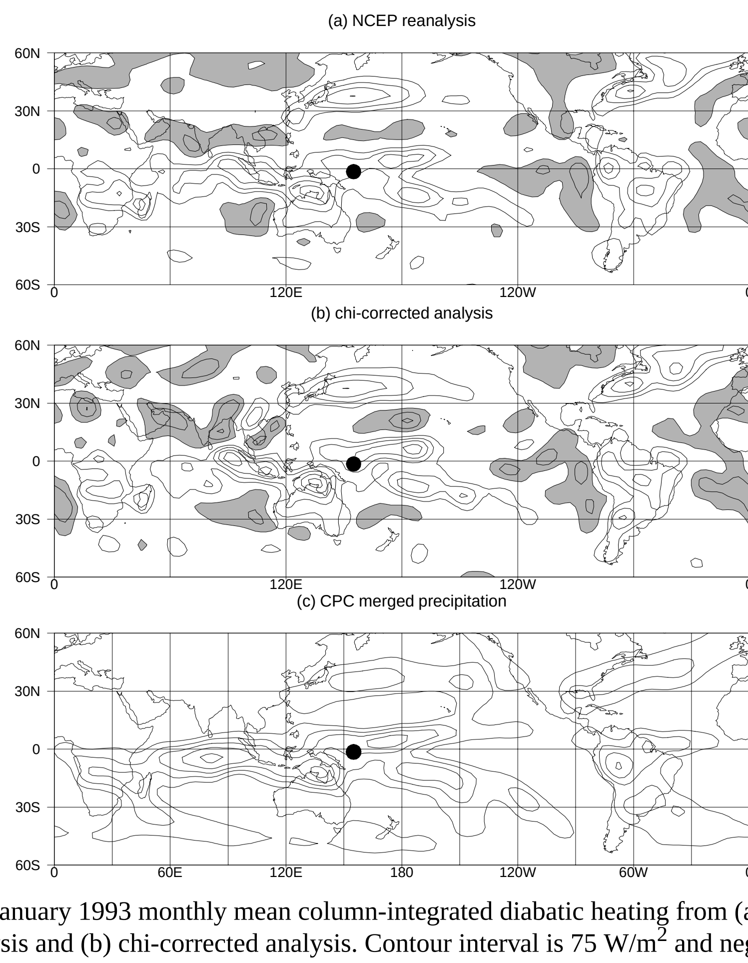

Fig. 2. January 1993 monthly mean column-integrated diabatic heating from (a) NCEP Reanalysis and (b) chi-corrected analysis. Contour interval is 75 W/m^2 and negative values are shaded. (c) CPC merged precipitation for January 1993. Contour interval is 3 mm/day. The solid circle indicates the Intensive Flux Array of COARE.

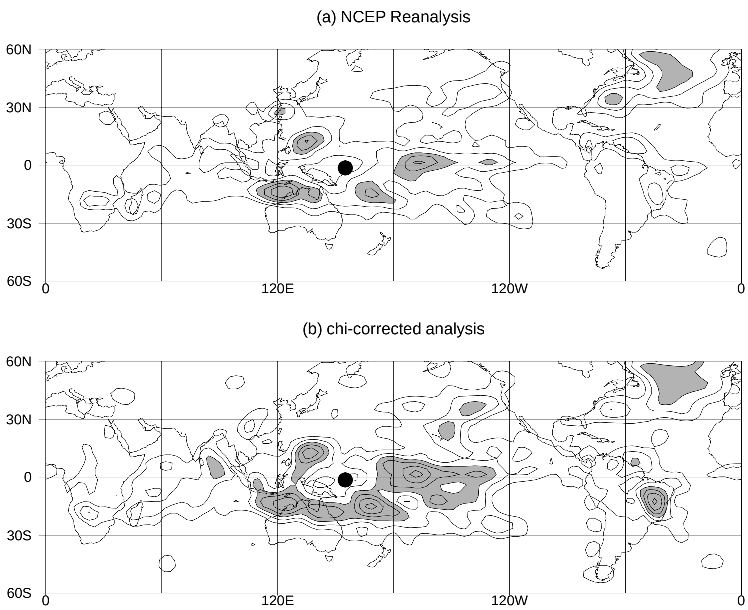

Fig. 3. Interannual standard deviation of column-integrated diabatic heating in January from (a) NCEP Reanalyses and (b) chi-corrected analyses. Contour interval is 15 W/m^2, no contours below 50 W/m^2 are plotted, and values greater than 80 W/m^2 are indicated by shading. The solid circle indicates the Intensive Flux Array region of COARE.

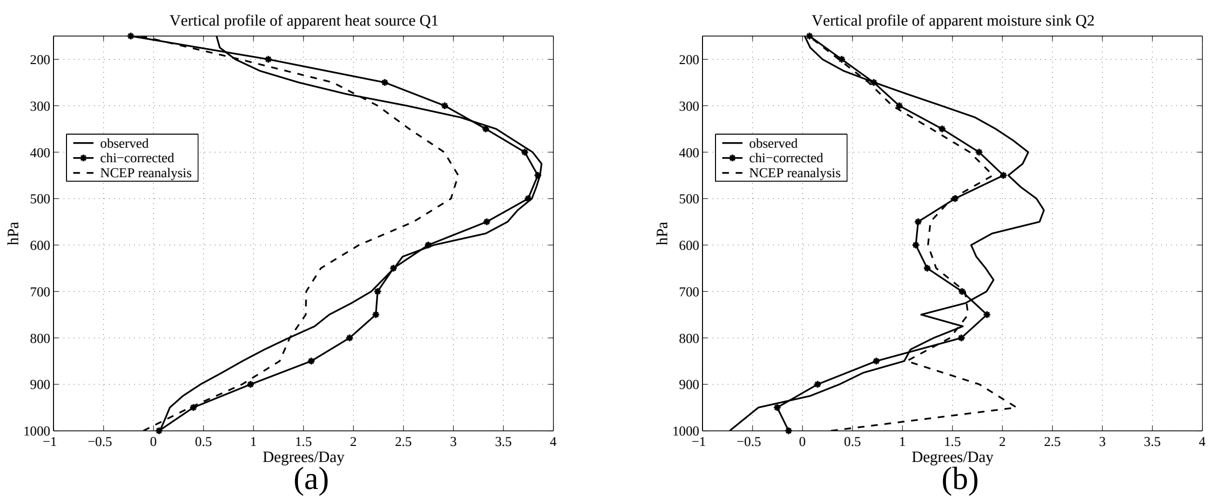

Fig. 4. (a) Vertical profile of seasonally averaged (1 Nov. 1992 - 28 Feb. 1993) heat source Q1 from observations (solid line), chi-corrected fields (circles), and NCEP Reanalysis (dashed line). Units are K/day. Observations taken from an updated version of Johnson and Lin (1997) over the Intensive Flux Array (IFA) of COARE. NCEP and chi-corrected fields are measured at an analysis gridpoint (1.4S, 155E) near the center of the IFA region. (b) As in (a) but for the moisture sink Q2.